

COMPARING FORCED-AIR TO RESISTIVE-POLYMER WARMING FOR PERIOPERATIVE TEMPERATURE MANAGEMENT: A RETROSPECTIVE STUDY

A thesis presented to the faculty of the Graduate School of
Western Carolina University in partial fulfillment of the
requirements for the degree of Master of Science in Nursing.

By

Brian Lindsey Lupo

Thesis Chair: Dr. Shawn Collins, PhD, DNP, CRNA
Associate Professor of Nursing
School of Nursing

Committee Members:
Ian Hewer, MSN, MA, CRNA
Vallire Hooper, PhD, RN, CPAN, FAAN

April 2018

ACKNOWLEDGEMENTS

I would like to personally thank my committee members for their support and encouragement. In particular, Dr. Shawn Collins motivated me to stay focused on the overall trajectory of the project. Ian Hewer served as a necessary sounding board from my initial concept development all the way to the end. He helped focus my work and guide my thinking as a researcher. This thesis could not have gotten off the ground without the support of Dr. Vallire Hooper. Her association with the research facility truly proved a great asset to my work. She was there every step of the way to guide me through the necessary approvals from IRB to nursing research committees. I thank all my committee members for their meticulous feedback on each draft of this thesis.

I owe a great deal of gratitude to the support of my family and peers. I sincerely thank my life partner, Aaron Cusick, for pushing me to keep going. His expertise on databases helped frame my understanding of data on a large scale. I also want to extend thanks to the countless conversations with anesthesia colleagues in the clinical environment. Their anecdotal reports sparked my initial project idea. Lastly, I recognize and duly appreciate the support from my mothers and father. Unfortunately, my father passed away before completion of this thesis. As a physician and father, he was very proud of my trajectory through anesthesia training—thanks Dad!

TABLE OF CONTENTS

List of Tables.....	v
List of Abbreviations.....	vi
Abstract.....	vii
Chapter One: Background and Rationale for Study.....	1
Introduction and Purpose.....	1
Justification of Study.....	2
Theoretical Framework.....	2
Scientific Rationale.....	3
Assumptions.....	3
Research Questions and Hypotheses.....	4
Definition of Terms.....	5
Chapter Two: Review of Literature.....	7
Introduction.....	7
Thermoregulation.....	7
Operating Room Environment.....	7
Effects of Anesthesia.....	8
Perioperative Temperature Management.....	9
Prewarming.....	11
Hypothermia Complications.....	12
Increased Cost.....	12
Adverse Effects.....	12
Cardiac Complications.....	12
Surgical Site Infections.....	13
Coagulopathy.....	13
Prolonged Anesthesia Recovery.....	14
Warming Devices.....	14
Forced-Air Warming Concerns.....	15
Ventilation Disruption.....	15
OR Temperature.....	16
Infection Concerns.....	16
Vector Potential.....	18
Efficacy of Warming Devices.....	18
Brandt et al. (2010)	18
Nieh & Su (2016)	19
John et al. (2016)	19
Rewarming Studies.....	20
Summary.....	20
Chapter Three: Methodology.....	22
Research Design.....	22
Setting.....	22
Population and Sample.....	22
Protection of Human Subjects.....	23

Data Collection.....	24
Data Analysis.....	24
Limitations.....	25
Chapter Four: Results.....	27
Sample Characteristics.....	27
Major Findings.....	29
Temperature.....	29
Starting Temperature.....	29
Final Temperature.....	29
Inadvertent Perioperative Hypothermia.....	29
Incidence of IPH.....	29
Hypothermia at Starting Temperature.....	30
Secondary Analysis.....	31
Chapter Five: Discussion.....	33
Summary of Findings.....	33
Generalizations.....	34
Implications of Limitations.....	35
Future Research Implications.....	37
Conclusions.....	38
References.....	39

LIST OF TABLES

Table 1. Sample Characteristics.....	28
Table 2. Perioperative Core Temperatures and the Incidence of IPH.....	31

LIST OF ABBREVIATIONS

List of Abbreviations

AORN: Association of periOperative Registered Nurses

ASA: American Society of Anesthesiologists

ASPAN: American Society of PeriAnesthesia Nurses

BMI: Body Mass Index

CDC: Centers for Disease Control and Prevention

CMS: Centers for Medicare & Medicaid Services

d: Cohen's *d*, effect size statistic

EMR: Electronic Medical Record

FAW: Forced-Air Warming

FDA: Food and Drug Administration

ICU: Intensive Care Unit

IPH: Inadvertent Perioperative Hypothermia

M: Mean

Mdn: Median

NICE: National Institute for Health and Care Excellence (UK)

PACU: Post-Anesthesia Care Unit

PHI: Protected Health Information

r: Pearson's *r*, measure of effect size

RHB: Resistive-polymer Heating Blanket

SSI: Surgical Site Infection

ABSTRACT

COMPARING FORCED-AIR TO RESISTIVE-POLYMER WARMING FOR PERIOPERATIVE TEMPERATURE MANAGEMENT: A RETROSPECTIVE STUDY

Brian Lindsey Lupo, RN, BSN, BA

Western Carolina University (April 2018)

Chair: Dr. Shawn Collins

Committee: Professor Ian Hewer and Dr. Vallire Hooper

Background: Forced-air warming and resistive-polymer heating blankets are both popular devices used to prevent inadvertent hypothermia in the perioperative patient. There are differing reports in the literature as to which method is most efficacious. We performed a retrospective, quasi-experimental study to compare the effectiveness of these devices at warming patients intraoperatively. The institution where the data were collected had switched from a forced-air to a resistive-polymer device for trial period, which provided a natural experiment for this study.

Methods: In this study, we collected data from 426 patients that had elective, non-spine orthopedic procedures. Data were extracted from electronic medical records on patients who received forced-air warming ($n = 119$) and on patients who were warmed with resistive-polymer heating blankets ($n = 307$). The documented intraoperative temperatures were used as the outcome measures for determining inadvertent perioperative hypothermia, final temperature, and temperature changes throughout the case.

Results: This study found that the use of forced-air warming was associated with a significantly higher final intraoperative temperature ($p = .001$, $d = .46$) compared with the resistive-polymer

heating blanket as a means of perioperative temperature management of non-spine, orthopedic patients. The incidence of hypothermia was not found to be significantly different between the groups at the final temperature ($p = .102$) or at anytime throughout surgery ($p = .270$). The forced-air warming group had a lower incidence of hypothermia at the end of the case among those that started hypothermic compared to the resistive heating group ($p = .023$). There was a moderate strength of association between the use of forced-air warming and a positive rise in temperature from the starting to final temperature ($p = .001$, $r = .22$). However, no causal relationship between warming device and temperatures or hypothermia incidence should be assumed.

CHAPTER ONE: BACKGROUND AND RATIONALE FOR STUDY

Introduction and Purpose

It is well established in the literature that inadvertent perioperative hypothermia (IPH) is a risk of anesthesia with sequelae that can be detrimental to the patient and their recovery (Kurz, Sessler, & Lenhardt, 1996; Malone, Genuit, Tracy, Gannon, & Napolitano, 2002). Perioperative hypothermia has been associated with coagulopathies, an increased risk of infection, morbidity related to myocardial events, and prolonged anesthesia recovery (Kurz et al., 1996; Wong, Kumar, Bohra, Whetter, & Leaper, 2007; Nesher et al., 2003; Sessler, 2016). Researchers have developed evidence-based strategies to combat IPH. Given the risk of patient hypothermia during surgery, it has become standard of care for patients to be actively warmed by means of a device to target a temperature between 36-37.5°C (Hooper et al., 2010).

There are two popular means for temperature management in the perioperative setting: forced-air warming (FAW) and resistive-polymer heating blanket (RHB). Reports in the literature vary on whether they are equally effective or whether one method may be more efficacious. A number of studies conclude that RHB is as efficacious or even superior to FAW (McGovern et al., 2011; Wood, Moss, Keenan, Reed & Leaper, 2014). A number of other reports in the literature have contradicted these results with findings that the FAW outperforms RHB (John et al., 2016; Sessler, Olmstead & Kuelpmann, 2011). The purpose of this study is to replicate a study by John et al. (2016) to compare the efficacy of two popular devices for perioperative temperature management: forced-air warming and resistive-polymer heating blanket.

Justification of Study

This retrospective, quasi-experimental study compares the efficacy of FAW blankets to RHB at temperature regulation in perioperative patients undergoing elective, non-spine orthopedic surgery under general or regional anesthesia. After a review of current literature, the authors found a discrepancy in the reported efficacy of one device over the other. This inconsistency in the literature leaves clinicians with incongruent recommendations regarding the best options for managing temperature in patients requiring anesthesia for surgery. This study seeks to add to the currently available literature via an investigational approach of temperature data retrieved retrospectively from one facility.

Theoretical Framework

The theoretical framework of this study is grounded in the work of Ernest Codman (1869-1940), a pioneer in quality improvement. Codman was a preeminent figure in the medical community related to his early work on quality improvement in hospitals. Dr. Codman helped to establish the American College of Surgeons (ACS) in 1913 with the stated objective of end-result system of hospital standardization (Darr, 2007; Howel & Ayanian, 2016). His work, known today as outcomes management of patient care, established hospital reform by tracking patient outcomes (Darr, 2007). Dr. Codman was a surgeon practicing at Massachusetts General Hospital in the 1890s when he began tracking outcomes of surgical procedures. He collected data and stratified variables based on organizational, clinician, and patient factors. In the event of a poor outcome or the identification of an error, he sought to correct variables that would lead to the prevention of future occurrences (Anderson, 2018; Darr, 2007).

Codman's work eventually led him to collect data on surgical patients, which was then made publically available for accountability purposes. This process, well known today, defied

the status quo in the early 20th century. Codman challenged other hospitals to do the same to track clinical outcomes (Darr, 2007). This study seeks to gather and analyze data on patients regarding perioperative temperature management with the explicit measurement of outcomes related to hypothermia. Retrospective data on surgical cases will be used to determine significant differences in intraoperative temperature among patients warmed with one of two warming methods. This use of data to observe end-result outcomes will help guide clinicians on intraoperative warming. Dr. Codman's work on quality improvement and outcome measurement permits a formidable framework within which to perform this research.

Scientific Rationale

The facility from which the data were collected evaluated a resistive-polymer warming device for 6 months. Prior to this time, forced-air warming was the standard perioperative warming method. There were anecdotal reports from anesthesia providers and PACU nursing staff that patients were arriving to the PACU with colder temperatures after the change to resistive-polymer blankets was executed. After the 6-month period, the facility returned to the use of forced-air warming devices. Ultimately, there was buy in from stakeholders at the facility to investigate discrepancies in the reports of intraoperative temperature management among the two devices. This evaluation of a new warming device at the facility represents a natural experiment of which the authors took advantage to study two popular warming devices.

Assumptions

Intraoperative temperature management is a key issue for anesthesia providers in the management of surgical patients. It is the standard of care to keep patients normothermic through the use of warming or cooling devices if indicated. Normothermia is defined as a core temperature between 36°C and 38°C (Hooper et al., 2010; NICE, 2008; Guiliano & Hendricks,

2017). IPH has been shown to have detrimental outcomes in the surgical population. Anesthesia providers must monitor temperature closely and intervene appropriately through the use of warming devices over the patient's body, intravenous (IV) fluid warmers, ventilator circuit warmers, ice packs, and/or cooling blankets depending on the patient's core body temperature.

Research Questions and Hypotheses

The research questions the authors of this study seek to answer are as follows:

- Is there a difference in the final intraoperative temperature on surgical patients whether a FAW or RHB was used for intraoperative warming?
- Is there an association between warming device used and the incidence of inadvertent perioperative hypothermia at the end of a procedure?
- Is there a significant difference in hypothermia at anytime throughout surgery among those warmed with FAW or RHB?
- For patients who are hypothermic at the start of the case, is either FAW or RHB associated with a significant change in the proportion of patients who are normothermic ($>36^{\circ}\text{C}$) by the end of the case?

The literature provides conflicting evidence on FAW versus RHB as it relates to temperature management. The authors predict there will be a statistically significant incidence of hypothermia at any point throughout the case and the final temperature among subjects warmed with RHB compared with the FAW device. The authors also predict there will be a significant difference among the final intraoperative temperatures between the two groups. Finally, among patients who start the case hypothermic, the authors predict a greater proportion of those patients will be normothermic by the end of the case among the FAW group compared to those warmed with RHB.

Definition of Terms

Active warming: When measures such as FAW or RHB are used to actively warm patients in the perioperative period.

Anesthesia providers: Healthcare providers licensed to administer anesthesia in the United States, includes anesthesiologists, certified registered nurse anesthetists, and anesthesiologist assistants.

Demographic characteristics: The factors within the population allowing for categorization (e.g., age, gender, BMI).

First intraoperative temperature: Due to high variability among the first documented intraoperative temperature (i.e., Temp1), the second documented temperature (i.e., Temp2, five minutes later) was used as the first intraoperative temperature. Reasons to explain this variability in temperature include a lag time in equilibration of the temperature monitoring probes with the patient's core temperature between Temp1 and Temp2.

Forced-Air Warming (FAW): A device that blows warmed air through a circuit connected to a disposable blanket that is placed over and/or under a surgical patient in order to warm patients via convective heat.

Inadvertent Perioperative Hypothermia (IPH): A condition when surgical patients experience a core temperature below 36° Celsius. ASPAN and AORN define normal core temperature to be 36-38° Celsius (AORN, 2017; Hooper, et al., ASPAN, 2010).

Post-Anesthesia Care Unit (PACU): Perioperative unit where surgical patients recover from anesthesia after surgery, typically before being discharged home or admitted to the hospital.

Postoperative temperature: For the purposes of this study, this is the last recorded temperature in the operating room. The data were pulled from the anesthesia documentation system, which is separate to the postoperative nursing record in the facility where the study was conducted.

Prewarming: When active warming measures such as the FAW or RHB are used in the preoperative period for at least 30 minutes prior to transport to the OR.

Temperature monitoring probe: A probe used by anesthesia providers to measure core temperature (e.g., esophageal, nasopharyngeal, tympanic membrane, and axillary skin probes).

Resistive-polymer Heating Blanket (RHB): A reusable blanket that provides conductive heat to maintain normothermia in surgical patients.

Surgical Site Infection (SSI): An infection that develops in the part of the body where surgery took place, which involves infections of the superficial skin or more deep tissues under the skin, organs, or implanted material (CDC, 2012).

CHAPTER TWO: REVIEW OF THE LITERATURE

Introduction

Inadvertent perioperative hypothermia (IPH) is now a well documented adverse effect of surgery and anesthesia if corrective measures are not used to maintain normothermia. Perioperative hypothermia is defined as a body core temperature below 36°C (Al-Qahtani & Messahel, 2011). The occurrence of IPH reported in the literature varies, but somewhere between 50-90% of patients experience a temperature below normal (Hegarty et al., 2009; Al-Qahtani & Messahel, 2011). Currently the standard is to use a warming device to actively warm patients during surgery to maintain normothermia. ASPAN and AORN define normothermia as between 36°-38°C, while NICE recommends stricter guidelines between 36.5°-37.5°C (Hooper et al., 2010; NICE, 2008; Guiliano & Hendricks, 2017). All three organizations agree in the definition of hypothermia as any temperature below 36°C. There are multiple factors as to why surgical patients become hypothermic when measures are not taken to prevent the loss of temperature.

Thermoregulation

Operating Room Environment

Surgery requires anesthesia in the form of general, regional, and/or local anesthesia. Any form of anesthesia can have a mild to profound effect on the body's thermoregulatory centers (Sessler, 2016; Diaz & Newman, 2015). Operating rooms are typically kept at a cooler temperature to decrease infection risk and to appease staff scrubbed into the case under many layer of scrubs, gowns, gloves, a surgical hat, and a mask. The air exchange inside a modern, laminar-flow operating room is typically rapid (at least 20 times per hour) to help prevent infection, so this causes a natural amount of air current blowing over exposed areas (Sessler et al., 2011). The patient often has a large exposure of skin to the cool environment after anesthesia

is induced to prepare the surgery area. Then, once the patient is draped for surgery, the area required by the surgeon must remain exposed to the cooler temperatures throughout surgery.

Effects of Anesthesia

General anesthesia and, to some extent, regional anesthesia results in the loss of the body's thermoregulatory mechanisms. This process begins at the induction of anesthesia with a subsequent drop in temperature post-induction. Volatile anesthetic gases along with common IV anesthetics such as propofol and opioids reduce vasoconstriction and shivering thresholds (Sessler, 2016). Reduced vasoconstriction allows blood vessels to dilate and blood flow distributes more widely to the periphery thereby increasing radiant heat loss through the skin. This redistribution of blood flow from the core to the periphery is one of the major reasons for such a profound reduction in core temperature (Sessler, 2016; Kurz et al., 1996).

The hypothalamus is the most important thermoregulatory center in the body (Nieh & Su, 2016; Sessler, 2011). Under normal conditions, drops in core temperature of only a few tenths of a degree activate vasoconstriction to counteract this change. This vasoconstriction threshold reduces from 36.5-37°C down to between 34-35°C at anesthetic doses of the volatile gases and IV anesthetics (Sessler, 2016). The shivering response to hypothermia normally occurs about 1°C below the vasoconstriction threshold. Shivering increases metabolic activity by a factor of five in order to raise core temperature (Eyolfson, Tikuisis, Xu, Weseen, & Giesbrecht, 2001). The range between vasoconstriction and shivering thresholds remains similar under anesthesia (i.e., shivering threshold is maintained about 1°C below vasoconstriction threshold). The mechanism to explain how anesthetics impair thermoregulation is not known (Sessler, 2016).

The literature suggests that the use of neuraxial blockade (e.g., spinal or epidural local anesthetics) or muscle relaxants each contribute to a lack of thermoregulation (Burger &

Fitzpatrick, 2009, Sessler 2016; Horosz & Malec-Milewska, 2013). Muscle relaxants, often used to facilitate intubation and to promote akinesia (i.e., loss of voluntary and involuntary movement to a painful stimulus) for surgery, interfere with nerve conduction to muscles. This muscle paralysis causes a decrease in thermogenesis by skeletal muscles (Giuliano & Hendricks, 2017; Sessler, 2016). Local anesthetics used for regional or neuraxial anesthesia cause vasodilation and increased radiant heat loss of the affected area. (Sessler, 2016; Horosz & Malec-Milewska, 2013). All of these in combination put surgical patients at significant risk of IPH.

Perioperative Temperature Management

Temperature monitoring varies according to the measurement site and equipment used. Sessler (2016) recommends core temperature monitoring from one of four sites for the most accurate thermal monitoring: pulmonary artery, distal esophagus, nasopharynx (probe inserted 10-20 cm), and tympanic membrane. Skin temperature varies widely, but, when used for certain patients, the axilla at the site above the axillary artery provides the most consistent measurement for skin temperature. Any patient receiving general anesthesia for more than 30 minutes or any patient with neuraxial anesthesia for a large operation should receive temperature monitoring (Hooper et al., 2010; Sessler, 2016). The ultimate goal in monitoring the temperature of surgical patients is to guide interventions to maintain normothermia.

Numerous professional organizations have published guidelines for preventing perioperative hypothermia. ASPAN, AORN and a British organization, NICE, each outline a variety of interventions to maintain normothermia throughout the perioperative period. All three organizations recommend monitoring a patient's core temperature in the setting of interventions to preserve or restore normothermia (Hooper et al., 2010; NICE, 2008; Giuliano & Hendricks, 2017). In order to maintain normothermia during surgery, ASPAN and AORN also recommend

interventions that include some type of warming device such as forced-air warming, radiant or resistive heating, warm IV and irrigation fluids, and/or increasing the OR temperature (Hooper et al., 2010; Giuliano & Hendricks, 2017). A thorough screening of a patient's hypothermia risk should be evaluated preoperatively (Bashaw, 2016). The ASPAN guidelines for perioperative temperature management, as one example, are listed below for each phase of care (Hooper et al., 2010):

Preoperative period:

- Check a temperature upon admission
- Limit skin exposure
- Implement passive thermal care
- Implement active warming measures (e.g., FAW, RHB) for hypothermic patients
- Maintain ambient temperature of 20-25°C
- Nonemergent patients to be normothermic prior to transfer to operating room (OR)

Intraoperative period:

- Maintain operating room temperature 20-25°C
- Implement passive warming measures for normothermic patients (e.g., blankets, plastic sheeting, and reflective "space blankets")
- Implement active warming measures (e.g., FAW) for those identified as hypothermic or a procedure scheduled to last greater than 30 minutes
- Implement alternative active warming measures, if needed (e.g., warmed IV fluids, RHB, warmed irrigation fluids)

Postoperative period:

- Measurement of core temperature every hour for normothermic patients and every 15 minutes for hypothermic patients
- Assess patient's thermal comfort
- Implement passive thermal care
- Maintain ambient temperature at or above 24°C
- Implement active warming measures if patient hypothermic
- Discharge patient from PACU only once normothermic

Prewarming

Active warming measures should be employed for hypothermic patients in the preoperative period. In addition, warming measures such as the use of FAW or RHB can be provided to normothermic patients. This is known as prewarming and should be provided for at least 30 minutes for maximal benefit (Hooper et al., 2010; Sessler, 2016; NICE, 2008).

Hypothermia typically occurs in patients after the induction of anesthesia without prewarming, even when a warming device is used in the operating room (Sun et al., 2015). Evidence supports prewarming of patients in the preoperative period to reduce the time period the patient is hypothermic (Vanni, Braz, Modolo, Amorim, & Rodrigues, 2003; Camus, Delva, Sessler, & Lienhart, 1995). Patients will also rewarm more quickly post-induction if prewarming is used (Vanni et al., 2003). A significant reduction in blood loss and the need for transfusion has been shown with the use of prewarming (Bock et al., 1998). Evidence suggests the following complications in the recovery period are reduced with the use of prewarming: increased incidence of IPH, the need for postoperative ventilatory support, increased intensive care unit (ICU) admissions, decreased patient comfort level, and an increase in anxiety (Mahoney & Odom, 1999; Abreu, 2011; Leeth, Mamril, Oman, & Krumbach, 2010).

Hypothermia Complications

Increased Cost

The cost to the patient and hospital for the sequelae of hypothermia are significant. Lenhardt et al. (1997) found the duration of postanesthetic recovery of those patients who suffered from hypothermia was on average up to 50 minutes longer than normothermic patients. This results in increased cost, and loss of available beds in PACU for new patients coming out of surgery. Evidence from a 1999 estimated cost analysis of the cost burden for IPH demonstrated an increase of \$2,500-\$7,000 per surgical patient in hospitalization costs (Mahoney & Odom, 1999). It should be noted that this analysis is dated, and the current costs are likely higher today. In addition to a higher cost, the literature supports that patients report lower satisfaction scores due to shivering and more discomfort if they wake up from anesthesia in a mildly hypothermic state (Lenhardt et al., 1997; Kurz et al., 1995). Patient satisfaction scores are now linked with hospital reimbursement rates, which can be negatively impacted by low satisfaction scores (CMS, 2017).

Adverse Effects

Cardiac complications. Many adverse effects are associated with hypothermia including morbidity and mortality related to cardiac events. Frank et al. (1997) performed a landmark RCT that found adverse myocardial events were three times more likely in hypothermic patients. This study included two groups of randomized subjects ($n = 300$): one normothermic group ($n = 127$) and one hypothermic group ($n = 143$) after exclusion criteria applied. At the time, routine thermal care provided passive warming measures (e.g., warm blankets), and a patient's temperature was allowed to drift down during surgery. The researchers in this study used routine care in the 1990s (i.e., no active warming measures used) on the hypothermic group.

For the normothermic group, FAW was implemented intraoperatively as an active warming measure and continued for two hours into the postoperative period. Postoperative ventricular ectopy was noted in 2% ($n = 3$) of normothermic patients and 8% ($n = 11$) for the hypothermic group ($p = .04$). A morbid cardiac event was noted in only 1% ($n = 2$) for normothermic patients and 6% ($n = 10$) for those in the hypothermic group ($p = .02$). Morbid cardiac events were defined as either unstable angina/ischemia, cardiac arrest, or myocardial infarction. This was the first study to look at thermal care in relation to cardiac events in a prospective manner and set the stage for more studies on the complications of hypothermia (Frank et al., 1997).

Surgical site infections. A significant reduction in core temperature causes vasoconstriction thereby potentially reducing blood flow to surgical incisions in need of oxygen and immune cells to fight off infection. Kurz et al. (1996) performed a randomized trial on colon resection surgery patients. The normothermic group was maintained at a normal temperature throughout surgery. The hypothermic group was maintained below 36°C for the duration of surgery and then warmed to a normal temperature in the postoperative period. They found a significant increase ($p = .009$) in surgical site infection (SSI) rates among the hypothermic group (19%) compared to the normothermic group (6%). This study was followed by another study in 2006 among general surgical patients with significant results ($p = .001$): SSI rates were 5% for normothermic patients and 14% for the hypothermic group (Melling, Ali, Scott, & Learper, 2001). The normothermic group rates of SSI for these studies correlate with the reported national average of 2-5% (Bratzler & Hunt, 2006).

Coagulopathy. Multiple studies have demonstrated an association with significant blood loss and IPH with ranges of blood loss from 200ml to well over 1000ml in hypothermic patients

compared to those maintained at normothermic temperatures (Wong et al., 2007; Hofer et al., 2005). Along with blood loss, the transfusion requirements of hypothermic patients have been documented as significantly higher than normothermic patients. Kurz et al. (1996) found in a study of 200 patients that the normothermic patients had an average transfusion requirement of 0.4 ± 0.4 L whereas the requirement of hypothermic patients was 1.1 ± 0.9 L ($p = .013$). In another study of 60 patients, the same results were replicated for hypothermic patients (Hofer et al., 2005). Substantial blood loss and transfusions carry significant risk to patients and, as demonstrated in this research, can be reduced by keeping patients normothermic.

Prolonged anesthesia recovery. The literature substantiates a strong association between prolonged postoperative recovery from anesthetic agents and hypothermia. Heier, Caldwell, Sessler & Miller (1991) found the duration of the muscle relaxant vecuronium extended from 28 minutes in the normothermic patient to 62 minutes ($p < 0.001$) in the mildly hypothermic patient. This was replicated with atracurium in another study with the duration extending 28 minutes longer ($p < 0.05$) for the hypothermic group (Leslie, Sessler, Bjorksten, & Moayeri, 1995). Plasma propofol concentration increased from 100% to 128% for normothermic and hypothermic patients, respectively (Leslie et al., 1995). All of these factors are cause for concern regarding OR turnover and PACU safety. Respiratory compromise resulting from lingering anesthesia in the postoperative period is a significant risk to the recovering surgical patient.

Warming Devices

There are two major available devices used for patient warming: forced-air warming and resistive-polymer heating blanket. The FAW system was originally developed in 1987 as a means to combat perioperative hypothermia and was the first of its kind. Up to 80% of hospitals in the US utilize forced-air warming devices (3M, 2012). It uses convective heating generated by

a reusable warm air blower that delivers warmed air into single-use blankets over or under patients. A popular conductive and radiant style heating blanket uses resistive-polymer technology via a reusable blanket attached to a temperature control box. These RHB devices have thermistor-type temperature sensors to monitor blanket temperature and shut off the blanket if it overheats (HotDog, 2008).

Forced-Air Warming Concerns

Ventilation disruption. One of the main concerns raised in the literature about FAW is the disruption of ventilation in the operating room. This issue has appeared in orthopedic surgery literature. McGovern et al. (2011) was one of the first such studies showing detergent bubbles released near the head of a draped manikin showed air currents were more toward the surgical field than with conductive fabric heating. The OR was ventilated in a laminar flow pattern, which is defined elsewhere as downward, unidirectional supply with returns at various heights in the room (Sessler et al., 2011). McGovern et al. (2011) had a surgeon and anesthesia professional in addition to the draped manikin patient but no OR traffic in the study room.

The McGovern et al. (2011) study was replicated by another group that showed similar motion of detergent bubbles over the surgical field with the use of FAW compared with no heating blanket and a conductive blanket (Belani, Albrecht, McGovern, Reed, & Nachtsheim, 2013). There were some significant limitation to this study. First, the study lacked a working surgical team in the room. Second, the overhead surgical lights were turned off so researchers could count bubbles effectively to determine airflow currents (Belani et al., 2013). Whyte and Shaw (1974) found that overhead lights do cause a disruption in airflow over surgical sites.

When smoke has been utilized instead of bubbles as a means of determining airflow in laminar flow ORs, the evidence demonstrated no significant difference in airflow disturbances

FAW and no heating device used (Sessler et al., 2011; Sharp, Chesworth, & Fem, 2002). Sessler et al. (2011) studied the airflow with the FAW upper-body blanket settings off, at ambient air, and on high (43°C) on a conscious, draped patient using aerosol particles of diethylexyl sebacate and a particle counter placed 10 cm above the patient's abdomen. No significant mean difference in particle concentration was detected between all three settings of the FAW device. Sharp et al. (2002) performed a study with similar results ranging from an empty OR to up to 4 volunteers with the FAW both on and off. They found no significant difference among particle concentrations under various conditions.

OR temperature. The effect of convection on the temperatures in the OR was studied and found to be increased with the use of FAW by Dasari, Albrecht, & Harper (2012). Floor-to-ceiling temperatures were measured in a laminar flow OR with a manikin patient. FAW, a conductive heating blanket over the patient, and an under body resistive heating mattress were all compared. The mean (SD) surgical site temperatures were increased with the use of FAW compared with the conductive blanket (+2.7°C, $p < 0.001$) and the resistive mattress (+3.6°C, $p < 0.001$). While the conclusion that increased temperatures at the surgical site may be of concern regarding airflow disturbances, this study was not setup to study airflow. The authors concluded that the pocket of warmer air above the surgical site is a result of a convection current in the laminar flow OR. While this might be the case, there was no association shown in this study between this increased temperature with FAW and an actual risk to patients. It should be noted that the conductive blankets were provided by the company that sponsored the study, and they paid for the costs of temperature mapping in this study (Dasari et al., 2012).

Infection concerns. Two studies of FAW have found an association with either an increase in SSI or an increased bacterial load in the patient. The first study was an opportunistic

study by McGovern et al. (2011) performed with 1437 patients undergoing hip replacement surgery. The authors defined SSI as an infection at the surgical site within 60 days of surgery, a definition that met the European Health Protection Agency criteria for deep infection (Horan, Gaynes, Martone, Jarvis, & Emori, 1992). The authors found a significant increase in deep joint infections when FAW was used compared to when a conductive fabric warming device was in use with an elevated infections odds ratio (3.8, $p = .024$).

The authors concluded that FAW was therefore not recommended for orthopedic surgery involving implants until further research was performed. However, the limitations in this study are profound. This was an observational study with no controls for confounding variables. There was also no mention of blood transfusions, incontinence, physical status, age, or diabetic status of the patients in each group. The authors also noted that during the study period a change in antibiotic and thromboprophylaxis protocols occurred (McGovern et al., 2011). These concerns are major internal validity issues that make any conclusions drawn from this research questionable.

Moretti et al. (2009) evaluated the risk of infection with FAW. They demonstrated an increased bacterial load with the use of FAW, but no nosocomial infections throughout the postoperative course. A sample size of 30 patients receiving non-cemented hip implantations were recruited for this study and split into two groups: those that received FAW ($n = 20$) and those that did not ($n = 10$). Bacterial load samples were obtained from both groups at multiple sites in the operating room and from the patient's skin at multiple time points. Although the bacterial load was found to be significant in the cases that received FAW, the bacterial load with the use of FAW was found to be no different than the bacterial load present upon moving the patient to the OR table.

The authors, Moretti et al., suggest that the use of FAW is no different than the presence of medical staff and their movements in the OR. There were no infections diagnosed in any of the patients throughout this study. Limitations of this study include the small sample size and the lack of detail regarding how infections were ruled out, although the patients were claimed to have been followed for six months (Moretti et al., 2009). The authors concluded that FAW poses no real risk of nosocomial infections and offers a real advantage in preventing the complications of hypothermia. A review article on infections and warming devices also found no association documented in the literature definitely showing a causal relationship between FAW and SSI (Kellam et al., 2013).

Vector potential. The established recommendations for FAW devices state to change the particle filter every 6 months (or 600 hours of operating time) and only to use the single-use perforated coverlet approved for the device (Avidan et al., 1997). In order to test the vector potential of FAW devices, the researchers organized an experiment in a vascular OR for two different types of FAW devices. The devices were set up to blow warm air over agar plates both with and without the provided blanket. They also swab tested the warming devices and hoses. They found when the recommendations were followed, no bacterial colonization was discovered on the agar plates. However, when the single-use blanket was not used, the researchers noted bacterial colonization with multiple species on the agar plates. Therefore, when the manufacturer's directions provided with FAW devices are followed, there is little to no risk of spreading flora through the device itself (Avidan et al., 1997).

Efficacy of Warming Devices

Brandt et al. (2010). A number of researchers have looked into the differences in efficacy of the different warming device systems. Brandt et al. (2010) compared RHB to FAW in

orthopedic patients and found no difference between the two comparing core mean temperatures, final temperatures, and duration of surgery among the groups. Two significant values were listed in this study. First, there was a significant difference in the genders between groups: FAW group had 16 males and 24 females, and the RHB group had 31 males and 9 females ($p < .01$). Second, the environmental temperature one meter from the warming device after 30 minutes was as follows: FAW $24.4 \pm 5.2^{\circ}\text{C}$ and RHB $22.6 \pm 1.9^{\circ}\text{C}$ ($p < .01$). Interestingly, though, the authors reported all other p values that were not significant as “ $p = \text{NS}$ ” instead of giving the exact value. They did, however, claim an alpha level $< .05$.

Nieh & Su (2016). The authors of this study performed a meta-analysis comparing FAW to RHB, circulating water methods and passive insulation. Twenty-nine trials were eventually included in this meta-analysis. FAW was found to be superior to passive insulation and circulating water mattresses; however, there was no statistical significance between FAW, RHB, and circulating water garments. There were several limitations of this meta-analysis, as noted by the authors. The highest Jadad Quality Score (JQS) of the articles included was only three out of a five-point score. This score is used to evaluate the quality of randomized trials (Jadad et al., 1996). There was also heterogeneity among many of the trials comparing the FAW to other warming devices. This was affected by timing of interventions, duration of surgery, anesthesia type, and sample size. (Nieh & Su, 2016). The issue is not settled in the literature, however, as there are still divergent findings.

John et al. (2016). They compared RHB to FAW in a randomized single-blinded study on 160 patients among various surgery types. The mean final temperature for the group that received RHB was 35.9°C ($SD\ 0.6$) and for the FAW group was 36.1°C ($SD\ 0.5$). The FAW group had a statistically significant higher temperature at the end of surgery ($p = .029$). The

number of patients with IPH at the end of surgery for the RHB group compared to the FAW group was 44 (54.3%) and 28 (35.9%), respectively. This was also found to be statistically significant ($p = .017$). It should be noted that no prewarming was performed on any of the subjects. If it were used the number of patients with IPH might have been lower. There was no appreciable difference in blood transfusion, total fluids or blood loss noted between the groups. SSI was not a variable followed in this study (John et al., 2016).

Rewarming studies. Two studies have found FAW to be superior to RHB when intraoperative rewarming was studied. Röder et al. (2011) studied 28 patients undergoing maxillary tumor surgery. After placement of invasive monitoring, patient temperatures were allowed to drop to 35°C before being randomly assigned to the RHB or FAW group. The RHB rewarmed the patients at about half the rate of FAW ($p < .001$), and the RHB group had a mean final core temperature below 36.0°C (Röder et al., 2011). Comparing 129 patients on cardiopulmonary bypass, Engelen et al. (2011) found that FAW was superior to RHB and passive interventions to rewarm the patient at the end of bypass ($p < .001$). These two studies show significant efficacy of FAW to rewarm patients who have become hypothermic.

Summary

Hypothermia is a well-documented risk of anesthesia and has the potential to cause significant harm to patients. Adverse effects of hypothermia include major myocardial events, coagulopathies, increased costs, infection, and prolonged recovery from anesthesia (Frank et al., 1997; Wong et al., 2007; Mahoney & Odom, 1999; Leslie et al., 1995; Sessler, 2016). ASPAN, AORN, and NICE all have published guidelines that advise clinicians on strategies to prevent IPH in the surgical population (Hooper et al., 2010; NICE, 2008; Guiliano & Hendricks, 2017). Vanni et al. (2003) found that prewarming reduced IPH at the end of surgery. ASPAN

recommends prewarming for those who are hypothermic and/or who will be in surgery for > 30 minutes (Hooper et al., 2010). Core temperatures must be monitored throughout the perioperative period, and active warming measures should be used during surgery to maintain a core temperature between 36-38°C (Hooper et al., 2010; Sessler, 2016). Multiple devices exist that can be used for active warming, such as forced-air warming, resistive-polymer heating blankets, and circulating water mattresses. There is ongoing debate in the literature regarding potential advantages and disadvantages of each device. No device or system remains more important in the clinical environment than a vigilant clinician to use a variety of methods to prevent hypothermia and its related sequelae.

CHAPTER THREE: METHEDOLOGY

Research Design

This was a retrospective, quasi-experimental study. The sample represented the population of surgical patients at one facility in the Southeast United States. There was no randomization of subjects in this study and no control groups, although the warming device groups are compared as means of treatment. This study is quasi-experimental given the natural experiment that occurred at the research facility. A trial of a resistive warming device (RHB) was instituted by the facility where the data were collected. The research team decided to create one group out of the RHB trial period, and the other group from a similar period of time when FAW was used exclusively.

Setting

The data were collected from the anesthesia documentation from the Electronic Medical Record (EMR) system at the facility. This facility is a tertiary referral center licensed for 763 beds with an orthopedic surgery volume of approximately 10,000 cases/year. Data were collected from July, 2016-September, 2017. While there are surgical residents in general and OB/GYN surgery, there are currently no orthopedic residents or fellowships. The anesthesia department includes anesthesiologists, CRNAs, and student registered nurse anesthetists, but no anesthesia resident program exists within the facility. This tertiary care facility has a robust quality improvement and nursing research department; however, it is not a primary academic center.

Population and Sample

The target population was surgical patients undergoing elective, non-spine orthopedic procedures. The first sample was obtained from those patients who received intraoperative warming via a resistive-polymer heating device from July-September 2016. The second sample

was obtained from those subjects who received intraoperative warming from a forced-air device from July-September 2017. Inclusion criteria consisted of those patients over the age of 18 years old presenting for orthopedic procedures who received intraoperative warming and core temperature monitoring.

Protection of Human Subjects

The authors received approval to proceed from the Nursing Evidence-Based Practice and Research Council at the facility where data were collected (May 16, 2017). This facility's Institutional Review Board (IRB) and the Western Carolina University IRB deemed this study as exempt (IRBnet ID# 1077322-1; August 29, 2017). The facility IRB determined the study did not meet the definition of human subjects research, and, hence, no consent was necessary to proceed with data collection.

All data were deidentified before being disseminated to the research team to safeguard protected health information (PHI). No patient identifying information was required for the data collection or analysis. The authors developed research protocols, submitted them to the IRB, and followed them meticulously to keep the dataset protected. The data were kept on a password protected computer and not disseminated to anyone outside of the research team. The IRB was kept up to date with all changes to the research protocol and proper documentation was submitted and approved for changes to the protocol. The only major change to the research protocol was the removal of exclusion criteria for emergency/trauma cases and pregnant patients. The dataset provided included no means to discriminate these factors, and the IRB deemed that this did not warrant a change from exempt status (February 18, 2018).

Data Collection

Data were collected from the EMR of patients via a database that the institution had developed for quality improvement. The dataset was collected, compiled, and deidentified prior to dissemination to the author. The following patient characteristics were extracted in order to compare groups: age, gender, and body mass index (BMI). The exclusion criteria were pediatric patients less than 18 years old and cases where the patient's core temperature was less than 35°C at the beginning of the case. The authors made the decision to exclude patients with a starting temperature of <35°C since the primary outcomes of this study were to evaluate the efficacy of each warming device in maintaining normothermia, treatment of mild hypothermia, and the avoidance of IPH at the end of the case. This was not a study to evaluate best warming methods for more severe hypothermia. Six months of total data were retrieved over two periods: July-September 2016 and July-September 2017.

Data Analysis

Data analysis was completed with SPSS 24.0 for PC (SPSS Inc, Chicago, IL, USA). Categorical data are reported as mean, median, IQR, and range as appropriate. The χ^2 test was used to analyze categorical data. In order to determine if there was a significant difference among the groups based on patient characteristics, statistics were reported on this data since the study is retrospective and not randomized. Histograms and the Shapiro-Wilk test were used to determine normal distributions for continuous data, and the Student's t-test was used for analysis if deemed normally distributed. When data were skewed the authors analyzed data with the Mann-Whitney U test. For analysis of pre-test/post-test data the McNemar's test was used to determine a significant change in proportions for each group from starting to final temperatures. The authors used a p -value of <0.05 as meeting the criteria for statistical significance. No

adjustment was applied to account for multiple testing since the planned number of comparisons was limited.

Limitations

There were a number of limitations that should be noted in this study. The temperature data in the facility is most often slaved into the EMR by the monitoring system, so this reduced the possibility of data entry errors; however, data such as age, BMI, and warming device type were based on data entered by clinicians. This opens the possibility of data entry errors. Unfortunately, the time period of FAW was used (i.e., July-September 2017) included no data for temperature monitoring device type (e.g., esophageal monitor, nasopharyngeal, or skin). As such, there could be no control over whether core temperatures were always measured appropriately. The time of warming device application was included in the data; however, there was no documentation of when or if the device was turned off prior to the end of the case. The warming device time reported in the patient characteristics in Table 1 is the calculated duration of time from the charted time of the device application to the end of the case.

The OR temperature data was not collected or included in this study. It is policy at the facility where the research was conducted for the temperature to be maintained between 68-73°F (20-22.7°C), with a minimum of 65°F (18.3°C). The authors did not have access to the individual OR temperatures. The ambient OR temperature is a potential confounding variable that was not controlled for or reported in this retrospective analysis. No assessment can be made on any significant difference among the FAW and RHB groups with respect to the temperatures in the OR for each case. This is a limit to internal validity of the study.

American Society of Anesthesiologists (ASA) physical status, anesthesia type (general and/or regional) blood transfusions, and total amount of IV fluids administered would be

appropriate data points to report in this study; however, this data was not available to the authors for statistical analysis. The authors originally planned to exclude pregnant and emergency cases from data analysis. It is unlikely many pregnant patients would be receiving orthopedic surgery unless the surgery was deemed a true emergency, but the data did not include a way to differentiate pregnancy status. There was also no data provided that included whether the case was an emergency or trauma case. These all are valid points of limitation in the study.

The groups included in the data analysis were disproportionate in their total number. This may be explained by omission of the warming device used within the charting system. At the facility where the data were collected, there was only one warming device in use during each period included. Resistive heating was used exclusively during July-September 2016 and FAW only during July-September 2017. It was standard of care at the facility to use active warming measures for most cases during the period the study took place. The authors used the charted warming device for inclusion purposes, so if there was not a warming device selected for a case then no assumption could be made to include cases without proper documentation. During the period when FAW was used, there were only 119 orthopedic cases that met the inclusion criteria for the study while the RHB had 307 cases.

Statistical analysis was limited at times because the data were skewed. This is likely a result two factors: clinical reality and non-randomized, retrospective data. The data were automatically extracted from the EMR via a database quality improvement program before being disseminated to the authors. As such, the authors did not perform a secondary, manual confirmation of the data against the EMR. In addition, there are bound to be confounding variables. These factors should be taken under careful consideration, and no assumption should be made regarding causality in this study.

CHAPTER FOUR: RESULTS

Sample Characteristics

The data provided for the RHB period (July-Sept. 2016) included 3841 cases, and the FAW period (July-Sept. 2017) included 3598 cases. The authors initially included 628 orthopedic cases that had a documented warming device type and were performed by non-spine orthopedic surgeons: RHB group $n = 429$ and FAW group $n = 199$. Pediatric cases (<18 yr., $n = 5$) were excluded. Cases with a starting temperature of $<35^{\circ}\text{C}$ ($n = 100$) were then excluded based on the exclusion criteria. The authors retained cases with discrete missing data that appeared to be have been a result of an isolated data collection issue, and these were recoded as such in the dataset as discrete missing values. Cases that included highly variable temperatures (e.g., $>1^{\circ}\text{C}$ changes over 5-10 mins) were extracted ($n = 4$). All cases with a significant missing data, such as little to no consistent temperatures, were extracted ($n = 89$). In the final analysis, 426 cases were included with 307 in the RHB group and 119 in the FAW group.

The sample characteristics for the study are presented in Table 1 for each group. The median age between the two groups includes the full range since the data were not normally distributed. The proportion of males and females in each group happened to have been equal, an occurrence that happened by chance. The median BMI for the RHB and FAW group was 29 with a similar interquartile range (IQR) and range. There were two extreme BMI outliers in the RHB group (63.0 and 72.6) that were retained since these BMIs are a clinical reality at this facility. No statistically significant difference was found between groups for gender, BMI, or age. Therefore, even though this was retrospective data, these reported characteristics were not significantly different between groups.

A Mann-Whitney U test was performed to determine if there was a significant difference in total OR time for each group. They were not found to be significantly different: RHB ($Mdn = 93, n = 307$), FAW ($Mdn = 82, n = 119$), $U = 16666, z = -1.40, p = .16, r = .06$. The time difference between warming device application and the time the patient entered the OR is reported as “time to warming device application.” This variable was calculated to assess for any difference among the groups during the time when there was no active warming at the start of the case: during anesthesia induction and the patient was being prepped and draped for surgery. The range was large (0-68 minutes) for all cases, but a Mann-Whitney U test did not show a significant difference between the groups on this variable; RHB ($Mdn = 93, n = 307$), FAW ($Mdn = 82, n = 119$), $z = -1.853, p = .064$. Medians instead of means reported on these data since they were not normally distributed and non-parametric tests were used for analysis of differences between both groups.

Table 1			
<i>Sample Characteristics</i>			
	Resistive heating (n=307)	Forced-air warming (n=119)	p-value
Patient characteristics			
Age (year)	65 (53–74[22–100])	67 (52–73 [18–91])	.999
Gender (male/female)	129/178	50/69	1.000 ^a
BMI (kg m ⁻²)	29 (25–34 [16–73])	29 (25–35 [17–54])	.875
Total OR time (min)	121 (96–158 [42–390])	112 (89–149 [43–383])	.166
Total warming device time (min)	93 (65–127 [11–355])	82 (58–122 [14–292])	.160
Time to warming device application	19 (12–27 [0–57])	21 (14–30 [3–68])	.064
<i>Note.</i> Values are median (IQR [range]) or number as appropriate.			
^a The proportion of males/females in each group is the same, an occurrence that happened by chance.			

Major Findings

Temperature

Starting temperature. An independent-samples t-test was conducted to compare the starting OR temperatures among the RHB and FAW groups. There was no significant difference in the starting temperature for RHB ($M = 36.2$, $SD = 0.5$) or FAW ($M = 36.2$, $SD = 0.7$) groups, $t(183) = -0.003$, $p = .998$ (two-tailed), $d = .02$. Levene's test indicated unequal variances ($F = 8.5$, $p = .004$), so degrees of freedom were adjusted from 424 to 183. The temperatures for each case were recorded every five minutes. The actual first temperature was up to 1-2°C lower than the second temperature, so the authors used the second temperature (i.e., Temp2, 5 minutes later) as the first OR temperature for statistical analysis. The clinical reason for this lag in temperature reading was likely due to temperature probe equilibration with the patient's core temperature.

Final temperature. An independent-samples t-test was performed to compare the final intraoperative temperature for the two warming device groups. A significant difference between the two warming device groups was found: RHB ($M = 36.2$, $SD = 0.6$) and FAW ($M = 36.5$, $SD = 0.7$), $t(424) = -3.95$, $p = .001$ (two-tailed), $d = .46$. Cohen's d falls between 0.2 (small effect size) and 0.5 (medium effect size), thus the magnitude of the differences in the means between the two warming groups is small-medium but not inconsequential (mean difference = -0.28, 95% CI : -0.42 to -0.14). The effect size helped to determine that the difference may have occurred outside of chance (Cohen, 1988).

Inadvertent Perioperative Hypothermia

Incidence of IPH. The incidence of hypothermia at the first recorded temperature was analyzed. There were no pre-induction temperatures in the dataset, so the authors were limited to "Temp2" as described above to report the incidence of hypothermia at the start of the case. A

Chi-square test for independence indicated no significant association between the incidence of hypothermia at the first temperature used and warming device group, $\chi^2 (1, n = 426) = 0.86, p = .354, \phi = .05$. The incidence of IPH at anytime was next analyzed. Among the RHB group, 173 (56.4%) of the patients warmed with RHB had IPH at some point, and 60 (50.4%) of the FAW group met the criteria for IPH. A Chi-square test for independence was conducted to assess for any association between warming device and the incidence of IPH at any point during the surgery. There was no significant association between RHB and FAW groups and the incidence of IPH at anytime., $\chi^2 (1, n = 426) = 1.22, p = .270, \phi = -.05$.

One of the main outcomes of the study was to assess the incidence of IPH at the final intraoperative temperature among each group. A Chi-square test for independence indicated no significant association between warming device type and the incidence of IPH at the final intraoperative temperature, $\chi^2 (1, n = 426) = 2.67, p = .102, \phi = -.07$. Therefore, the initial hypothesis that there would be a significant difference between the groups and IPH at the end of the case was not supported.

Hypothermia at starting temperature. A McNemar's test was performed on each of the two warming device groups to assess for a significant difference in the proportion of cases that were hypothermic at the end compared to those hypothermic at the beginning of the case. This test examined whether there was a change in the proportion of the sample that was hypothermic prior to and following the warming device used. Each of the variables were categorical, and hypothermia ($<36^{\circ}\text{C}$) was coded as 0 (for "absent") and 1 (for "present"). The test showed that the RHB group had no significant change in the proportion of cases that were hypothermic at the end of the procedure (35.2%) when compared with the proportion of cases who were hypothermic at the beginning (32.2%), $p = .362$, two-sided. The FAW group did exhibit a

significant difference in the proportion of cases in each group who were hypothermic at the end (27.7%) compared with the proportion of cases who were hypothermic at the beginning (37.0%), $p = .023$, two-sided. It should again be noted that there was not a significant difference in the incidence of IPH at the starting temperature among the groups.

Table 2			
<i>Perioperative Core Temperatures and the Incidence of IPH</i>			
	Resistive heating (n=307)	Forced-air warming (n=119)	p-value
Parameter			
Starting OR temperature (°C)	36.2 (0.5)	36.2 (0.7)	.998
Final OR Temperature (°C)	36.2 (0.6)	36.5 (0.7)	.001
Difference in Final and Starting temperatures	-0.05 (-0.35–0.29 [-1.28–1.29])	0.17 (-0.13–0.17 [-1.34–1.94])	.001
IPH at Start	99 (32.2%)	44 (37.0%)	.354
IPH at anytime in OR	173 (56.4%)	60 (50.4%)	.270
IPH at Final temperature	108 (35.2%)	32 (26.9%)	.102
<i>Note.</i> Values are mean (SD), median (IQR [range]), or number (proportion) as appropriate.			

Secondary Analysis

The authors desired to quantify this change in temperature from starting to final temperature. Upon secondary analysis, a Mann-Whitney U test revealed a significant difference in the temperature change between the final and starting temperature among the RHB group (mean rank = 196.50, $Mdn = -0.05$, $n = 307$) and FAW group (mean rank = 257.36, $Mdn = 0.17$, $n = 107$), $U = 13047.5$, $z = -4.58$, $p = .001$, $r = .22$. Since statistical significance was found, the direction of the difference suggested by the mean rank favors FAW as having a more significant change in temperature from beginning to end. The effect size of this difference was calculated

via the Cohen (1988) criteria ($r = .22$) and, as a result, there was a moderate strength of association of FAW and a more positive rise in temperature from beginning to the end of the procedures. The variable for this was test was created utilizing the last recorded OR temperature minus the starting OR temperature (i.e., Temp2) in order to determine the difference for each case. The analysis was performed factoring by RHB and FAW group. The distribution for this data was skewed, so the Mann-Whitney U test was used instead of the independent-samples t-test and medians are reported.

CHAPTER FIVE: DISCUSSION

Summary of Findings

This study found that the use of forced-air warming was associated with a significantly higher final intraoperative temperature ($p = .001$) compared with the resistive-polymer heating blanket as a means of perioperative temperature management of non-spine, orthopedic patients. This finding is consistent with prior findings by John et al. (2016), who found that FAW had significantly higher final temperatures compared with RHB. The incidence of hypothermia at anytime ($p = .270$) or at the end of the procedure ($p = .102$) were not found to be significantly different among the FAW and RHB groups. The incidence of hypothermia at the final temperature contrasts to what John et al. (2016) found. In that study a significant difference in the incidence in IPH at the end of surgery was found between FAW and RHB. As a method of rewarming patients who met hypothermic criteria at the start of the case, FAW was associated with a lower proportion of those patients that had a final temperature of $<36^{\circ}\text{C}$ ($p = .023$). This evidence is consistent with the work of Röder et al. (2011) and Engelen et al. (2011). Both of these studies found that the use of FAW to be superior to RHB when used as a means to rewarm hypothermic patients.

The authors conclude there was a significant increase in temperature between starting and final temperature among the FAW group compared with the RHB group. The clinical significance of this finding should be considered given that both groups had a mean final intraoperative core temperature $>36^{\circ}\text{C}$. Although this study found a significant difference among final temperatures between the RHB and FAW groups, the incidence of IPH at the final intraoperative temperature did not reach significance. There was, however, a moderate strength of association between FAW and the significant temperature change from beginning to the end

of the case for FAW ($p = .001$, $r = .22$). This strength of this association between FAW and the difference in starting and final temperatures helps to support the phenomenon that this change may have occurred outside of chance, although no assumption can be made regarding causation.

Generalizations

The redistribution of blood flow from the core to the periphery through the vasodilation caused by general and regional anesthetics are a major cause of the significant reduction in core temperature (Sessler, 2016). On top of this radiant heat loss, the body's response to hypothermia (e.g., reduced shivering threshold, reduced vasoconstriction) is weakened due to the impairment of normal thermoregulation mechanisms these same agents cause (Giuliano & Hendricks, 2017). The implications for patients that experience hypothermia are of real consequence. Literature suggests increased morbidity and mortality related to hypothermia during the perioperative period, including the following: increased myocardial events, coagulopathies, increased blood transfusion rates, and increased risk of infections (Frank et al., 1997; Wong et al., 2001; Melling et al., 2001). Costs to organizations for preventable complications such as SSI are not reimbursed. Evidence from 1999 estimated cost analysis of hypothermia suggests the cost to patients and healthcare organization can reach up to \$7,000 (Mahoney & Odom, 1999). Given the rise in costs this dated analysis likely underestimates the current cost of hypothermia complications. Clinicians must be cognizant of maintaining a patient's core temperature between 36-38°C by utilizing the most effective tools available to counter the multitude of factors that place the perioperative patient at risk for hypothermia.

Professional organizations such as ASPAN and British guidelines published by NICE both recommend that any case over 30 minutes should receive active warming measures to prevent IPH (Hooper et al., 2010; NICE, 2008). Evidence suggests prewarming should be

provided to patients when time allows in the preoperative period for at least 30 minutes prior to the induction of anesthesia. For patients who present with a temperature $<36^{\circ}\text{C}$, clinicians should initiate active warming measures in order to reach normothermia prior to transferring to the OR (Hooper et al., 2010; NICE, 2008). It is vital that anesthesia providers have effective methods available to actively warm patients in the OR after the induction of anesthesia to maintain normothermia.

Active warming has been standard perioperative care for years as a means to prevent and treat inadvertent perioperative hypothermia (Hooper et al., 2010; NICE, 2008; Guiliano & Hendricks, 2017). Forced-air warming has been in use since the late 1980s with positive results well-documented in the literature (Hynson & Sessler, 1992; Röder et al., 2011, Engelen et al., 2011; Hooper et al., 2010). Resistive-polymer heating blankets have gained in popularity in the temperature management of surgical patients and have also been supported by the literature (Brandt et al., 2010; Nieh & Su, 2016). Possible advantages of RHB cited in the literature include a potential but not well-substantiated decreased infection risk, less noise than FAW, and the reusability of blankets as a means to deter ongoing costs (McGovern et al., 2011) These issues were not included as a part of this study but do warrant future research regarding the different options available to provide perioperative warming to surgical patients.

Implications of Limitations

There were a number of limitations of this study. While temperature data were automatically charted by the monitoring system in the OR, there were a number of data points (e.g., age, BMI, warming device type) that relied on manual data entry. This opens the possibility of data entry error at the point of contact with the patient, which is a possible issue concerning internal validity. The OR temperature was not included in this study and was a potential

confounding variable. There was no way to report a significant difference in OR ambient temperature between groups. Also, the groups included in the study were disproportionate. The FAW sample was lower ($n = 119$) compared to the RHB ($n = 307$) sample, and there was no obvious reason for a discrepancy in orthopedic cases for the same time period. This might be explained by a lack of proper documentation of the warming device used. Any cases that had no warming device charted were not captured during the inclusion process.

A number of issues in the data limited the analysis. Education at the outset of the trial period for RHB was not ideal per anecdotal reports from clinicians. This could have had a potential impact on how it was used, and the authors did not have the means to quantify this effect as a potential confounding variable. There was no charted temperature probe type for the period the FAW was in use, so the authors were not able to report this as a variable. Although, most clinicians use core temperature monitoring with general anesthesia at the facility. In the case of regional and/or neuraxial anesthesia an axillary skin temperature is standard. No PACU temperatures were available for the FAW period. This limited the final intraoperative temperature as the last temperature for analysis. Neither group had a pre-induction temperature included in the data, which may explain the high incidence of hypothermia at the starting OR temperature of 32.2% for RHB and 37.0% for FAW. The total amount of IV fluids, any blood products administered, and the use of a fluid warmer could impact the overall temperature; however, this data was not captured in the dataset available to the researchers.

Resistive heating consisted of a posterior warming blanket typically pre-warmed to 39°C prior to the patient being moved OR table. This provided partial warming coverage during the time before and immediately after the induction of anesthesia. An upper or lower body blanket was then typically applied on top of the patient before draping to provide additional warming

according to the standards during the trial period. For most adult patients who received FAW, the upper or lower body coverlet was not typically applied until the patient was completely prepped and draped for surgery. This difference in practice could have contributed to a discrepancy in the overall incidence of IPH for patients and the final intraoperative temperature. However, the authors reason that this discrepancy represents clinical reality and may actually strengthen external validity. Even with these clinical limitations, this study found that the FAW group still had a statistically significant higher final temperature.

Future Research Implications

Future research should include more prospective clinical trials to limit confounding variables. Further assessment is warranted on the performance of resistive heating compared to forced-air warming, such as the study performed by John et al. (2016). It would be warranted to perform even larger randomized trials to continue this research. Close control of times between entering the OR, anesthesia induction, and application of the warming device would strengthen internal validity of future studies. Future research might include a more complete temperature record including pre-induction and PACU core temperatures. It would also be warranted to include a logistic or multivariate regression model to assess for predictive factors for IPH among both groups.

It would be prudent for future research to account for the amount of hypothermic time throughout the procedure. This would allow a more accurate determination if one warming device outperforms the other in the total time the patient remains $<36^{\circ}\text{C}$ rather than just the incidence of hypothermia as a single variable. Data points in future research might include variables that are documented risks of hypothermia, including blood transfusion rates, incidence of SSI, reports of adverse myocardial events, and patient thermal comfort level postoperatively.

Perioperative temperature management is a complex issue that affects surgical patient outcomes. Ernest Codman's early work on quality improvement continues to shape how we perform end-result systems research to improve surgical outcomes (Darr, 2007).

Conclusions

In conclusion, this study found that forced-air warming resulted in significantly higher final intraoperative temperatures compared to resistive-polymer heating blankets ($p = .001$). The authors of this study also concluded that FAW was associated with a significant difference in final temperatures $>36^{\circ}\text{C}$ in patients who were hypothermic at the start ($p = .023$). These supported the hypotheses stated at the outset of the study. The hypotheses not supported included the following: that there would be a significant difference among the FAW and RHB groups in the incidence of IPH during surgery ($p = .270$) and at the final temperature ($p = .107$). A surprising proportion of patients in both groups, though, experienced hypothermia during surgery (FAW 50.4%, RHB 56.4%) and at the final temperature (FAW 26.9%, RHB 35.2%). It should be noted that no causal relationships should be assumed from the findings. Future research should focus on how FAW, RHB, other methods, or a combination of these could be utilized to best prevent inadvertent perioperative hypothermia.

REFERENCES

- 3M. (2012). 3M Bair hugger forced-air warming celebrates 25 years in hospitals [Press release]. Retrieved from: <http://news.3m.com/press-release/company/3m-bair-hugger-forced-air-warming-celebrates-25-years-hospitals>
- Abreu, M.M. (2011). New concepts in perioperative normothermia: From monitoring to management. *Anesthesiology News Special Edition*, October 2011.
- Al-Qahtani A.S., & Messahel F.M. (2011) Benchmarking inadvertent perioperative hypothermia guidelines with the National Institute for Health and Clinical Excellence. *Saudi Medical Journal* 32(1), 27–31.
- Anderson, P. (2018). Theoretical approaches to quality improvement. In J.B. Butts & K.L Rich (Eds.), *Philosophies and theories for advanced nursing practice* (5th ed. pp. 375-391). Burlington, MA: Jones & Bartlett Learning.
- Avidan, M. S., Jones, N., Ing, R., Khoosal, M., Lundgren, C., & Morrell, D. F. (1997). Convection warmers--not just hot air. *Anaesthesia*, 52(11), 1073-1076.
- Bashaw, M. A. (2016). Guideline Implementation: Preventing Hypothermia. *AORN Journal*, 103(3), 304-313. doi:10.1016/j.aorn.2016.01.009
- Belani, K. G., Albrecht, M., McGovern, P. D., Reed, M., & Nachtsheim, C. (2013). Patient warming excess heat: The effects on orthopedic operating room ventilation performance. *Anesthesia and Analgesia*, 117(2), 406-411. doi:10.1213/ANE.0b013e31825f81e2
- Bock, M., Müller, J., Bach, A., Böhrer, H., Martin, E., & Motsch, J. (1998). Effects of preinduction and intraoperative warming during major laparotomy. *BJA: The British Journal of Anaesthesia*, 80(2), 159-163.

- Brandt, S., Oguz, R., Hüttner, H., Waglechner, G., Chiari, A., Greif, R., & ... Kimberger, O. (2010). Resistive-polymer versus forced-air warming: comparable efficacy in orthopedic patients. *Anesthesia and Analgesia*, 110(3), 834-838.
doi:10.1213/ANE.0b013e3181cb3f5f
- Bratzler, D.W., & Hunt D.R. (2006). The Surgical infection prevention and surgical care improvement projects: national initiatives to improve outcomes for patients having surgery. *Clinical Infectious Diseases*, 43(3), 322-330.
- Burger, L., & Fitzpatrick, J. (2009). Prevention of inadvertent perioperative hypothermia. *British Journal of Nursing*, 18(18), 1114-1119.
- Camus, Y., Delva, E., Sessler, D. I., & Lienhart, A. (1995). Pre-induction skin-surface warming minimizes intraoperative core hypothermia. *Journal of Clinical Anesthesia*, 7(5), 384-388.
- Centers for Disease Control and Prevention (CDC). (2012). Health-care associated infections: Surgical site infection (SSI). Retrieved March 30, 2018 from:
<https://www.cdc.gov/hai/ssi/ssi.html>
- Centers for Medicare & Medicaid Services (CMS). (2017). HCAHPS: Patients' perspectives of care survey. Retrieved March 30, 2018 from: <https://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/HospitalQualityInits/HospitalHCAHPS.html>
- Cohen, J.W. (1988). *Statistical power analysis for the behavioral sciences* (2nd edn). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Darr, K. (2007). Quality Improvement: The Pioneers. *Hospital Topics*, 85(4), 35-38.

- Dasari, K. B., Albrecht, M., & Harper, M. (2012). Effect of forced-air warming on the performance of operating theatre laminar flow ventilation. *Anaesthesia*, 67(3), 244-249. doi:10.1111/j.1365-2044.2011.06983.x
- Diaz, V., & Newman, J. (2015). Surgical Site Infection and Prevention Guidelines: A Primer for Certified Registered Nurse Anesthetists. *AANA Journal*, 83(1), 63-68.
- Engelen, S., Himpe, D., Borms, S., Berghmans, J., Van Cauwelaert, P., Dalton, J. E., & Sessler, D. I. (2011). An evaluation of underbody forced-air and resistive heating during hypothermic, on-pump cardiac surgery. *Anaesthesia*, 66(2), 104-110. doi:10.1111/j.1365-2044.2010.06609.x
- Eyolfson, D. A., Tikuisis, P., Xu, X., Weseen, G., & Giesbrecht, G. G. (2001). Measurement and prediction of peak shivering intensity in humans. *European Journal of Applied Physiology*, 84(1-2), 100-106.
- Frank, S. M., Fleisher, L. A., Breslow, M. J., Higgins, M. S., Olson, K. F., Kelly, S., & Beattie, C. (1997). Perioperative maintenance of normothermia reduces the incidence of morbid cardiac events. A randomized clinical trial. *Journal of the American Medical Association*, 277(14), 1127-1134.
- Giuliano, K. K., & Hendricks, J. (2017). Inadvertent perioperative hypothermia: current nursing knowledge. *AORN Journal*, 105(5), 453-463. doi:10.1016/j.aorn.2017.03.003
- Hegarty, J., Walsh, E., Burton, A., Murphy, S., O'Gorman, F., & McPolin, G. (2009). Nurses' knowledge of inadvertent hypothermia. *Journal of Advanced Perioperative Care*, 4(1), 33-42.

- Heier, T., Caldwell, J. E., Sessler, D. I., & Miller, R. D. (1991). Mild intraoperative hypothermia increases duration of action and spontaneous recovery of vecuronium blockade during nitrous oxide-isoflurane anesthesia in humans. *Anesthesiology*, 74(5), 815-819.
- Hofer, C. K., Worn, M., Tavakoli, R., Sander, L., Maloigne, M., Klaghofer, R., & Zollinger, A. (2005). Influence of body core temperature on blood loss and transfusion requirements during off-pump coronary artery bypass grafting: a comparison of 3 warming systems. *The Journal of Thoracic and Cardiovascular Surgery*, 129(4), 838-843.
- Hooper, V. D., Chard, R., Clifford, T., Fetzer, S., Fossum, S., Godden, B., & ... Wilson, L. (2010). ASPAN's evidence-based clinical practice guideline for the promotion of perioperative normothermia: second edition. *Journal of PeriAnesthesia Nursing: Official Journal of the American Society of PeriAnesthesia Nurses*, 25(6), 346-365.
doi:10.1016/j.jopan.2010.10.006
- Horan, T., Gaynes, R., Martone, W., Jarvis, W., & Emori, T. (1992). CDC definitions of nosocomial surgical site infections, 1992: a modification of CDC definitions of surgical wound infections. *Infection Control & Hospital Epidemiology*, 13(10), 606-608.
- Horosz, B., & Malec-Milewska, M. (2013). Inadvertent intraoperative hypothermia. *Anesthesiology Intensive Therapy*, 45(1), 38-43. doi: 10.5603/AIT.2013.0009
- HotDog. (2008). Technical brochure PN M103 Rev A. Retrieved from:
<http://hotdogwarming.com/wp-content/uploads/M103-HotDog-Technical-Brochure-EN.pdf>
- Howell, J., & Ayanian, J. (2016). Ernest Codman and the end result system: A pioneer of health outcomes revisited...Ernest Amory Codman. *Journal of Health Services Research & Policy*, 21(4), 279-281. doi:10.1177/1355819616648984

- Hynson, J.M., & Sessler, D.I. (1992). Intraoperative warming therapies: A Comparison of three devices. *Journal of Clinical Anesthesia*, 4(3): 194-199.
- Jadad A.R., Moore R.A., Carroll D., Jenkinson C., Reynolds D.J., Gavaghan D.J. & McQuay H.J. (1996) Assessing the quality of reports of randomized clinical trials: Is blinding necessary? *Controlled Clinical Trials*, 17(1), 1–12.
- John, M., Crook, D., Dasari, K., Eljelani, F., El-Haboby, A., & Harper, C.M. (2016). Comparison of resistive heating and forced-air warming to prevent inadvertent perioperative hypothermia. *British Journal of Anaesthesia*, 116(2), 249-254.
- Kellam, M. D., Dieckmann, L. S., & Austin, P. N. (2013). Forced-air warming devices and the risk of surgical site infections. *AORN Journal*, 98(4), 353-369.
doi:10.1016/j.aorn.2013.08.001
- Kurz, A., Sessler, D. I., Narzt, E., Bekar, A., Lenhardt, R., Huemer, G., & Lackner, F. (1995). Postoperative hemodynamic and thermoregulatory consequences of intraoperative core hypothermia. *Journal of Clinical Anesthesia*, 7(5), 359-366.
- Kurz, A., Sessler, D.I., & Lenhardt, R. (1996). Perioperative normothermia to reduce incidence of surgical-wound infection and shorten hospitalization. *New England Journal of Medicine*, 334(19), 1209-1215.
- Leeth, D., Mamaril, M., Oman, K., & Krumbach, B. (2010). Normothermia and patient comfort: a comparative study in an outpatient surgery setting. *Journal of PeriAnesthesia Nursing*, 25(3), 146-151. doi:10.1016/j.jopan.2010.03.010
- Lenhardt, R., Marker, E., Goll, V., Tschernich, H., Kurz, A., Sessler, D. I., & ... Lackner, F. (1997). Mild intraoperative hypothermia prolongs postanesthetic recovery. *Anesthesiology*, 87(6), 1318-1323.

- Leslie, K., Sessler, D. I., Bjorksten, A. R., & Moayeri, A. (1995). Mild hypothermia alters propofol pharmacokinetics and increases the duration of action of atracurium. *Anesthesia and Analgesia*, 80(5), 1007-1014.
- Mahoney, C., & Odom, J. (1999). Maintaining intraoperative normothermia: a meta-analysis of outcomes with costs. *AANA Journal*, 67(2), 155-164.
- Malone, D.L., Genuit, T., Tracy, J.K., Gannon, C., & Napolitano, L.M. (2002). Surgical site infections: reanalysis of risk factors. *Journal of Surgical Research*, 103(1), 89-95.
- McGovern, P.D., Albrecht, M., Belani, K.G., Nachtsheim, C., Partington, P.F., Carluke, I., & Reed, M.R. (2011). Forced-air warming and ultra-clean ventilation do not mix. *Journal of Bone and Joint Surgery*, 93-B(11), 1537-44.
- Melling, A. C., Ali, B., Scott, E. M., & Leaper, D. J. (2001). Effects of preoperative warming on the incidence of wound infection after clean surgery: a randomized controlled trial. *Lancet* (London, England), 358(9285), 876-880.
- Moretti, B., Larocca, A. V., Napoli, C., Martinelli, D., Paolillo, L., Cassano, M., & ... Pesce, V. (2009). Active warming systems to maintain perioperative normothermia in hip replacement surgery: a therapeutic aid or a vector of infection? *The Journal of Hospital Infection*, 73(1), 58-63. doi:10.1016/j.jhin.2009.06.006
- National Institute of Clinical Evidence (NICE). (2008). Clinical practice guideline: The management of inadvertent perioperative hypothermia in adults. Retrieved January 2, 2018 from <https://www.nice.org.uk/guidance/cg65>
- Nesher, N., Zisman E., Wolf, T., Sharony, R., Bolotin, G., David, M., Uretsky, G., & Pizov, R. (2003). Strict thermoregulation attenuates myocardial injury during coronary artery

- bypass graft surgery as reflected by reduced levels of cardiac-specific troponin I. *Anesthesia & Analgesia*, 96(2), 328-335.
- Nieh, H., & Su, S. (2016). Meta-analysis: effectiveness of forced-air warming for prevention of perioperative hypothermia in surgical patients. *Journal of Advanced Nursing*, 72(10), 2294-2314. doi:10.1111/jan.13010
- Röder, G., Sessler, D. I., Roth, G., Schopper, C., Mascha, E. J., & Plattner, O. (2011). Intraoperative rewarming with Hot Dog(®) resistive heating and forced-air heating: a trial of lower-body warming. *Anaesthesia*, 66(8), 667-674. doi:10.1111/j.1365-2044.2011.06722.x
- Sessler, D. I. (2016). Perioperative thermoregulation and heat balance. *Lancet*, 387, 2655-2664. doi:10.1016/S0140-6736(15)00981-2
- Sessler, D.I., Olmstead, R.N., & Kuelpmann, R. (2011). Forced-air warming does not worsen air quality in laminar flow operating rooms. *Anesthesia & Analgesia*, 113(6), 1418-1421.
- Sharp, R.J., Chesworth, T., & Fern, E.D. (2002). Do warming blankets increase bacterial counts in the operating field in a laminar-flow theatre? *The Journal of Bone and Joint Surgery (British)*, 84(4): 486-488.
- Sun, Z., Honar, H., Sessler, D. I., Dalton, J. E., Yang, D., Panjasawatwong, K., & ... Kurz, A. (2015). Intraoperative core temperature patterns, transfusion requirement, and hospital duration in patients warmed with forced air. *Anesthesiology*, 122(2), 276-285. doi:10.1097/ALN.0000000000000551
- Vanni, S. D., Braz, J. C., Módolo, N. P., Amorim, R. B., & Rodrigues, G. J. (2003). Preoperative combined with intraoperative skin-surface warming avoids hypothermia caused by general anesthesia and surgery. *Journal of Clinical Anesthesia*, 15(2), 119-125.

- Whyte, W., & Shaw, B. H. (1974). The effect of obstructions and thermals in laminar-flow systems. *The Journal of Hygiene*, 72(3), 415-423.
- Wong, P. F., Kumar, S., Bohra, A., Whetter, D., & Leaper, D. J. (2007). Randomized clinical trial of perioperative systemic warming in major elective abdominal surgery. *The British Journal of Surgery*, 94(4), 421-426.
- Wood A.M., Moss, C., Keenan, A., Reed, M.R., & Leaper, D.J. (2014). Infection control hazards associated with the use of forced air warming in operating theatres. *Journal of Hospital Infection*, 88(3):132-40.